Heat transfer and pressure drop in cross-flow welded plate heat exchanger for ammonia synthesis column

L.L. Tovazhnyanskyy[1], P.O. Kapustenko[1], O.Yu. Perevertaylenko[1], G.L. Khavin[2], O.P. Arsenyeva[1], P.Yu. Arsenyev[2]
[1] National Technical University "Kharkiv Polytechnical Institute", Dep. Of Integrated technologies Processes and Apparatuses, 21 Frunze st., Kharkiv, 61002, Ukraine; tel. +380577202223, e-mail: kap@kpi.kharkov.ua;
[2] AO SPIVDRUZHNIST-T LLC, Krasnoznamenny per. 2, off. 19, 61002, Kharkiv, Ukraine; tel. +380577202278, e-mail: o.p.arsenyeva@gmail.com.

Efficient heat recuperation is of primary importance in resolving the problem of efficient energy usage and consequent reduction of fuel consumption and greenhouse gas emissions. Plate Heat Exchanger (PHE) is one of the modern efficient types of compact heat transfer equipment. The principles of the construction and design for different types of PHEs are sufficiently well described in literature, see e.g. Klemes et al. (2015). The conventional type is plate-and-frame PHE, which was initially developed for the food industry and later proved efficient in many other applications. However due to elastomer gaskets the range of plate-and-frame PHE application is limited to pressures up to 25 bar and temperatures up to 180 °C and working fluids friendly to gaskets material. Besides, the cost of the gaskets, especially for severe working conditions, can dramatically increase the cost of heat exchanger as a whole unit. To widen the PHE application range by excluding elastomer gaskets the brazed (BPHE) and welded (WPHE) types of PHE were developed. Here the results of research on the thermal and hydraulic performance of WPHE of special design for high pressures and temperatures are presented.

The construction of investigated WPHE is developed for work in high pressure shell of ammonia synthesis column at pressure up to 32 MPa and temperature up to 520 °C. It consists of the stack of round corrugated plates with diameter 626 mm, which are welded together to form a number of channels for cold and hot streams exchanging heat. The welded collectors of special design are organizing multi pass movement of both streams with overall counter flow. The movement of two streams in one pass block is cross flow. Compare to the flow of streams in conventional plate-and-frame PHE there is significant difference. From hydraulic point of view the stream is entering the channel through almost full cross section, while in channels of plate-and-frame PHE it is entering from distribution collector of small diameter compare to channel width. It causes much smaller local hydraulic resistance at the port zone of WPHE and ensures even flow distribution across channel width. But for the heat transfer cross flow of streams causes the reduction of mean temperature difference compare to counter flow in one pass of plate-and-frame PHE. The overall counter flow in WPHE is making this loss in mean temperature difference smaller, but still this cross flow feature for individual passes should be accounted in correct PHE design. The available literature data are not directly applicable, as the level of fluid mixing across PHE channel is not known.

The heat transfer and pressure drop in WPHE were investigated experimentally using the model consisted of 16 plates representing the block of plates in one pass of WPHE. The thermal and hydraulic characteristics of this model were measured at specially developed test rig with water as test fluid for both streams. The results of experiments were compared with predictions by Equations proposed by Arsenyeva et al. (2012). It confirmed the validity of these equations for PHE channels of different geometry in case of cross flow. It is also estimated the dependence of PHE heat transfer effectiveness (ε) from the number of heat transfer units (NTU) in one pass of WPHE with cross flow of streams. The method for calculation of WPHE with overall counter flow and cross flow inside separate pass is developed.

The validity of the proposed Equations and developed method for WPHE design was confirmed by comparison with the data of tests on WPHE installed in ammonia synthesis column at industrial enterprise of ammonia production. WPHE was installed in existing synthesis column of ammonia unit instead shell-and-tube heat exchanger. The use of WPHE instead shell-and-tube unit enable to cut down the volume occupied by heat exchanger in high pressure shell of ammonia synthesis column and allows increase of the volume of catalyst. It leads to 15% rise of ammonia output.

Key words: plate heat exchanger, ammonia synthesis column, heat transfer, pressure drop.

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